1999

REQUIREMENTS COMPARISON HIT-TO-KILL VS WARHEAD FOR TMD

Authors
Ali Sleiman, THAAD Project Office, Huntsville, AL
JL Harris, KBM Enterprises Inc., Huntsville, AL

ABSTRACT

There has been recent interest in usage of conventional blast fragmentation warheads in a TMD role. This interest implies a perception that this approach would be easier to accomplish than Hit-To-Kill (HTK), and would yield comparable lethality. The first part of this perception is true at low closing velocity but at high closing velocity it may not be true due to extreme difficulty in performing the target detection function in sufficient time to support warhead fragment flight time requirements. The second part can never be true; regardless of engagement situation, warheads lack the lethality potential of direct hit, for interceptor sizes which deserve comparison. Attempts to achieve very high lethality with narrowly focused warheads result in even more stringent target detection requirements, requiring data and estimation accuracy approaching that of HTK. The requirements and considerations of warhead usage will be illustrated with simple geometric sketches and explained in this paper, in terms of required data, data accuracy, and required timeline.

The great disparity in potential lethality will also be explained.

BACKGROUND

Historically, almost all air defense missile systems have utilized warheads as the main lethal mechanism. This is true for one of the oldest systems, HAWK; the more recent PATRIOT; as well as a current Navy system, SM 2 Block 4 A. These systems were all originally designed to counter aircraft, and have all been considered for defense against missiles. Warheads of such missiles are capable of inflicting lethal damage to aircraft, even at relatively large miss distances. The interpretation of lethal, however, varies with the requirements and goals of the defense. Aircraft are large targets with many distributed vulnerable elements, some of which are vital to mission continuation, kill of others results in rapid loss of control with catastrophic results, and kill of some may result in immediate destruction of the aircraft. In actuality, mission abandonment without dispersal of payload (bombs) would be a very good engagement outcome, except for the possibility of repair and reuse. Both of the other two outcomes result in the payload being deposited randomly, and certainly non-optimally, but with a possibility of damage to defended assets. In no case has the missile/warhead been designed to immediately destroy the payload of the aircraft, even though some payloads were nuclear and highly lethal. Rarely could a payload from such a "killed" aircraft have produced damage near the intended target.

Defense against ballistic missiles is very different from defense against aircraft because the missile is put onto a trajectory to the intended target, early on, and will go there unless diverted. This is true even for the fragments of a shattered ballistic missile. Fragments having a low ballistic coefficient may fall considerably short of a point target, but still impact in the defended area. The payloads of ballistic missiles may contain conventional high explosive material in unitary or submunition form, or nuclear packages; but they also may contain chemical or biological agent in unitary or submunition form. The submunitions from such payloads may remain lethal on ground impact, even if dislodged from the missile by defensive attack. The unitary chemical agent may also produce a hazard on the ground, even when attacked defensively, and has certainly posed a difficult analysis problem to determine with confidence just what the result on the ground will be.

The debris footprint from such damaged ballistic missile payloads (of mass destruction) has potential to be large; therefore there has been much emphasis in recent missile defense programs on maximizing damage to the payload of the ballistic missile. The Hit-To-Kill approach was adopted by almost all missile defense programs started in the last decade. Much testing and modeling has been accomplished to support design of the HTK candidates, and to support evaluation of their lethality in terms of payload contents destruction. This assessed lethality is high, given a hit, and it degrades rapidly to zero if the payload is not overlapped by the Kill Vehicle (KV), as it must. Larger KV can tolerate greater miss distances than small KV, of course, since their radius is greater.

Given the lack of recent successes in achievement of HTK, prior to 15 March 99, questions were posed to the missile defense project offices relative to usage of warheads in their ballistic missile defense systems. This implied a perception that equal, or at least acceptable, lethality could be obtained by use of a warhead and that the problems of such usage would be less than those of HTK achievement. The remainder of this paper attempts to illustrate the problems associated with usage of a warhead to achieve high lethality against a ballistic missile payload of mass destruction.

INTERCEPT GEOMETRY

Figure 1 illustrates a planar intercept. As shown, the target and interceptor collide with zero miss distance. A line of sight (LOS) is indicated between the two bodies, and does not rotate in space perceptibly during this short portion of the endgame. In fact, generally, LOS rotation rate is derived in the on-board-homing sensor processing,

and countered by guidance maneuvers. This is the basis of Proportional Navigation. The LOS is indicated here because the velocity of the interceptor relative to the target lies along the LOS. Since the guidance sensor must "look" at the target, it is generally pointed along the LOS, and the angle between the missile centerline and the LOS is the required gimbal angle. The angle between the target centerline and the relative velocity is the strike angle and is important to lethality. The strike angle is also the viewing or aspect angle to the target and very important to target signature. The strike velocity is very important to lethality, especially against robust targets. In the absence of angle of attack, both the KV and the target centerlines would be aligned with their velocity vectors. Figure 2 illustrates the endgame geometry for a missile with a warhead. Projectiles are ejected from the missile, roughly normal to its centerline.The projectiles have a static pattern with opening angle as indicated. This would be observed from a warhead arena test, using witness plates. When expelled from a moving missile to hit a moving target, the projectile pattern relative to the target is as indicated by Vsl and Vse. The dispersion angle has become narrower, and varies from one side of the missile to the other. Of course only a planar view of the projectiles relative to the target is shown, and historically projectiles have been ejected all around the circumference of the missile. Note that the strike angle and strike velocity of the projectiles relative to the target vary considerably from one side to the other. Note also that the target velocity, missile velocity, and the crossing angle may all vary considerably over the suite of engagements against which a single missile may be required to operate. This leads to a great variation in projectile striking conditions, and greatly complicates the target detection/warhead detonation-timing problem.

In order for the projectiles to impact the target, the miss distance must be estimated and the actual direction of miss taken into account. For the classical air defense system this is done with a dedicated Target Detection Device (TDD). TDD may be active or passive RF antenna/receivers, IR, EO, laser, or even magnetic. Typically the elements are conformal to the external surface of the missile. In these cases it is difficult to achieve target detection patterns which are narrow about the missile centerline, or selectable, or steerable. TDD could be mounted on the guidance sensor, in principle, but physical space limitations, signal blockage, and possible electrical or signal interference seems to preclude this in practice. Figure 3 illustrates the target detection problem, using the same basic intercept situation. Here an interceptor missile is shown, sliding along the relative velocity vector, to pass between two targets. One target will be missed such that the interceptor crosses its path after point of closest approach; this is the Late Bird (LB) case. The other target will be missed such that the interceptor crosses its path prior to point of closest approach; this is the Early Bird (EB) case. Vsl represents the center of the projectile pattern, relative to the target, for the LB case. If the warhead were detonated with the missile at the indicated position, Vsl would pass into the target payload area. However, the TDD pattern is as indicated and the target cannot be detected until its nose tip enters the detection cone. Vsl then passes about two target lengths behind the payload, and does no harm. For the EB case, the warhead should have been detonated as indicated at the lower left. Since the TDD pattern would have already swept over the target, from rear to front, this case will be a success for the TDD—provided it has sufficient detection range. This illustration of target detection is notional of course, but not so much so as to be misleading. The wide variation in endgame geometry results in an extremely challenging situation for detection in high closing velocity situations.

Figure 4 shows warhead detonation range as a function of relative velocity and miss distance for a zero crossing angle and a low projectile ejection velocity (perhaps appropriate for a massive projectile). The effect of detonation timing error is also shown. As previous figures have shown, crossing angle would require a late-bird/early-bird adjustment.

Figure 3 illustrated that a steerable TDD pattern would be desirable, but this would be unnecessary if the TDD function could be performed with the information collected by the guidance sensor. This has been considered, and judged feasible by some. The necessary data are range and range rate, and two angles and their rates. Range and range rate could be measured directly by some sensors but might have to be provided by other means for other sensors. Angle data could be measured/derived by all seeker systems. The advantage of this approach, called seeker based or guidance integrated, "fuzing" is that the sensor is pointed toward the target throughout the terminal phase of guidance and can collect and process data over a relatively long time, if this is beneficial. In general, the seeker does have a "blind range" beyond which it can no longer collect good tracking data. Guidance continues based on last data values and extrapolations. The fuzing calculation must be made based on these last values and extrapolations also. The data collected by a sensor is not perfect. In general the errors in the data are greater at long range and decrease as range squared decreases. Errors do not go to zero however, as Figure 5 illustrates for angle error. No numerical scale is shown for obvious reasons. Rate data may be measured directly, for instance by doppler radar, or as a gimble rate but it may also be obtained as the derivative of position data, a noise amplifying process. Regardless, the miss distance vector must be estimated with data available before the blind range is reached, and that data must be

used to calculate the time at which to detonate the warhead so that the projectiles will traverse the miss distance and impact the target payload.

The forgoing discussion has attempted to make the point that fuzing a warhead correctly against a high-speed target, over a wide range of interceptor/target velocity is an extremely difficult problem. For this reason many warheads have had wide static dispersion patterns for the projectiles, as well as a variation in projectile ejection velocity, even against high speed aircraft, in order to increase hit probability.

PAYLOAD KILL REQUIREMENTS

The payloads of concern to TMD include the weapons of mass destruction (WMD), as mentioned in the background section, as well as conventional high explosive payloads. These payloads must all be "killed" with a high confidence. This means that a TMD interceptor must be capable of doing catastrophic damage to a large percentage of the payload contents, for a high percentage of the hit points which it achieves. HTK can produce this catastrophic damage to a WMD payload, given a good hit. Figure 6 shows the remains of a chemical submunition payload representation, after impact by a THAAD KV representation, at approximately 2 Km/sec on a sled track. This dictates a very stringent accuracy requirement, adopted as a goal by all TMD HTK programs. The degree to which this may eventually be achieved is not the subject of this paper, rather the purpose is to show that achievement of this catastrophic kill requirement may not be made any easier by adopting a warhead approach. Preceding paragraphs have discussed the problems of properly fuzing a warhead, but we have not yet addressed the characteristics which such a warhead must have to achieve kill comparable to HTK.

Figure 7 shows the remains of a chemical submunition payload representation after being "engaged" by a modern blast fragmentation side spray warhead. The warhead detonation was timed very precisely to place fragments onto the payload package. The fragments were large, on the order of .05 kg, and about 1 kg of fragments impacted into the payload section. The payload was cut into two pieces, but a fairly low percentage of the submunitions were catastrophically damaged. This level of damage does not compare well to that achievable with successful HTK.

The payloads of most concern contain submunitions which are individually hard (difficult to penetrate), and numerous. As a design goal, each must be penetrated by projectiles. The payloads may be attacked in the end game over a wide range of strike angles, from nose-on to 90 degrees (perhaps more). At nose-on the submunitions present the extreme penetration challenge, and forward tiers or bays will shield rear tiers, but the physical size presented by the payload is minimum. At 90 degrees, outer submunitions shield inner submunitions, but not to the degree for nose on. The maximum payload area is presented, and must be covered by projectile impacts to insure that all submunitions are damaged. Thus there is a payload penetration depth requirement driven by payload depth as viewed nose on, and a pattern size requirement driven primarily by payload length and maximum strike angle. Pattern size is also driven by the uncertainty associated with information processing, since the projectile pattern must be large enough to account for uncertainties in target estimated position (miss distance vector estimation error). Figure 8 shows some parametrics to illustrate that the total mass of the projectiles required may be considerable. Number of projectiles for pattern coverage is shown as a function of pattern diameter and projectile spacing. Total mass is then shown as a function of total number required and individual projectile mass. Individual mass on the order of 100 grams may be required to achieve the deep penetration, and a spacing on the order of a submunition radius is likely to be dictated to insure enough hits with good enough obliquity for penetration, and to reach rear submunitions through the inter-submunition spaces. Taken altogether, these argue for a required total mass of projectiles on the order of several tens of kilograms.

Clearly, the high hit density on target cannot be achieved except by using tightly focused warheads. A classical blast fragmentation side spray warhead which met the requirement would be prohibitively large. Focused warheads have been investigated with success by some researchers, and that technology is sufficiently mature to support consideration. Focusing adds another dimension of required accuracy to the problem. The miss distance vector had to be estimated already, even with the omni-directional warhead, because the optimum detonation timing varied between the EB and LB cases. The new dimension is directing the focused warhead effects in the proper direction, while the timing accuracy requirement remains as stringent as ever.

Figure 9 illustrates that the miss vector may be anywhere in the miss distance plane, thus requiring the warhead to direct projectiles up, down, left, or right, as the case may be, with equal probability. Seekers are commonly aimed toward the target by gimbaling, but warheads are rarely gimbaled due to their large mass and high moment of inertia. Warhead effects may be directed by other means, such as rolling the missile, or explosively. This latter means has the advantage of being relatively fast, but it is incremental. The direction of effects may be chosen to be 0, 20, 40 etc.degrees, for example, but no intermediate values are selectable. This is an obvious complication.

Finally, Figure 10 illustrates the error in the miss distance vector estimate. The error in estimated magnitude leads to errors in warhead detonation timing, making the pattern early or late relative to the payload. The direction error results in misdirecting the focused projectile pattern such that the payload may be missed or only partially covered. There will be error in the miss distance vector estimate; how much error depends on many factors. Obviously, the larger the error in the estimate relative to the miss distance, the more directionality is lost. This poses a special problem for usage of warhead projectiles to augment HTK damage, because the miss distance must be very small, and if the direction is not estimated correctly the projectiles will be wasted.

IMPLICATIONS OF A WARHEAD SOLUTION

All the foregoing rationale is meant to point out the difficulty of a warhead solution to this problem, not to claim that such a solution is impossible. If it were possible to do the target detection early enough, the miss vector estimation accurately enough, and the warhead focusing and aiming accurately enough, a high percentage payload contents kill could be high percentage payload contents kill could be high percentage payload contents kill could be achieved. The warhead required to achieve it would need several tens of kilograms of projectiles in its pattern, and additional mass for high explosive, containment, initiation, and projectile directing. The total vehicle mass would be a minimum of three to four times greater than the warhead itself, assuming a separated kill vehicle. As illustrated in Figure 11, total missile mass is influenced by the burnout velocity achieved and the specific impulse (ISP) of the propulsion system. Curves are shown for three values of ISP, ignoring drag and gravity, and some actual system data is also shown, below the curve for the lowest ISP value. It can be observed that an interesting burnout velocity will require a burnout mass ratio on the order of five, thus the total missile mass, including booster, will be on the order of fifteen to twenty times greater than the mass of the warhead alone. The total mass of an HTK missile with equivalent lethality would be a factor of three to four less.

SUMMARY

This paper has attempted to show that achievement of a high percentage payload contents kill by warhead usage is a complicated undertaking, perhaps equivalent in difficulty to achievement of HTK. Further, the total mass of the missile employing such a warhead will be three to four times greater than the total mass of a HTK missile. Therefore pursuit of HTK should not be abandoned lightly.

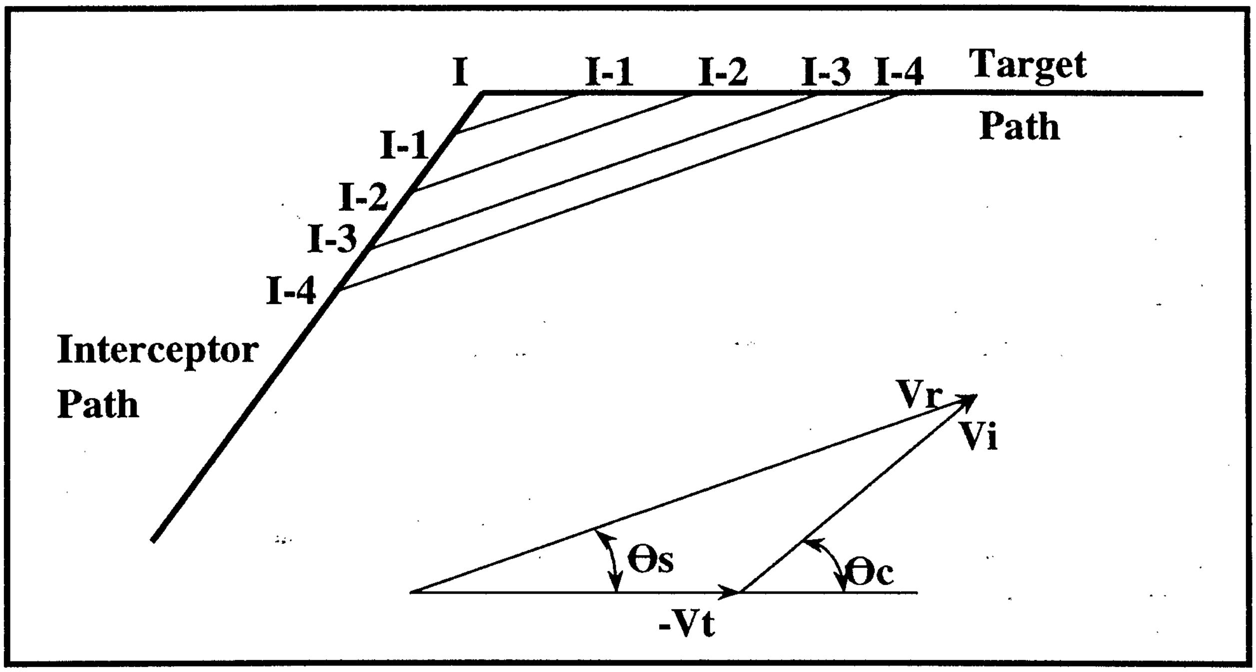


Figure 1. (U) Intercept Geometry

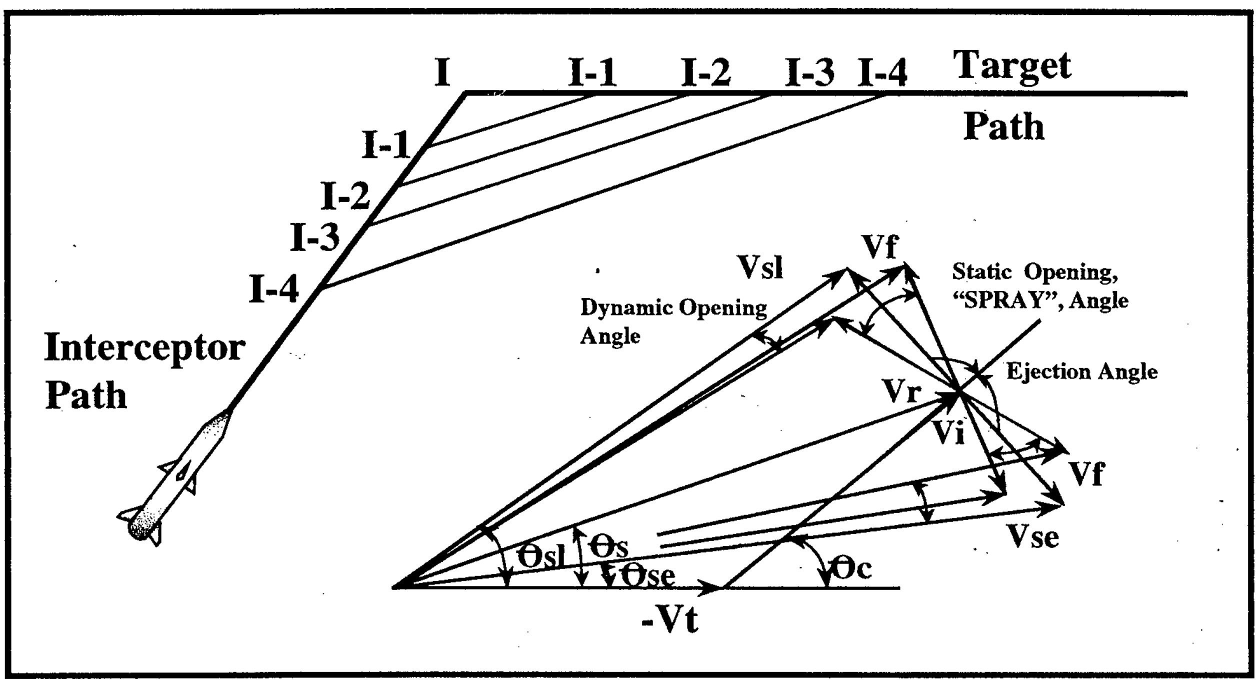


Figure 2. (U) Warhead Intercept Geometry

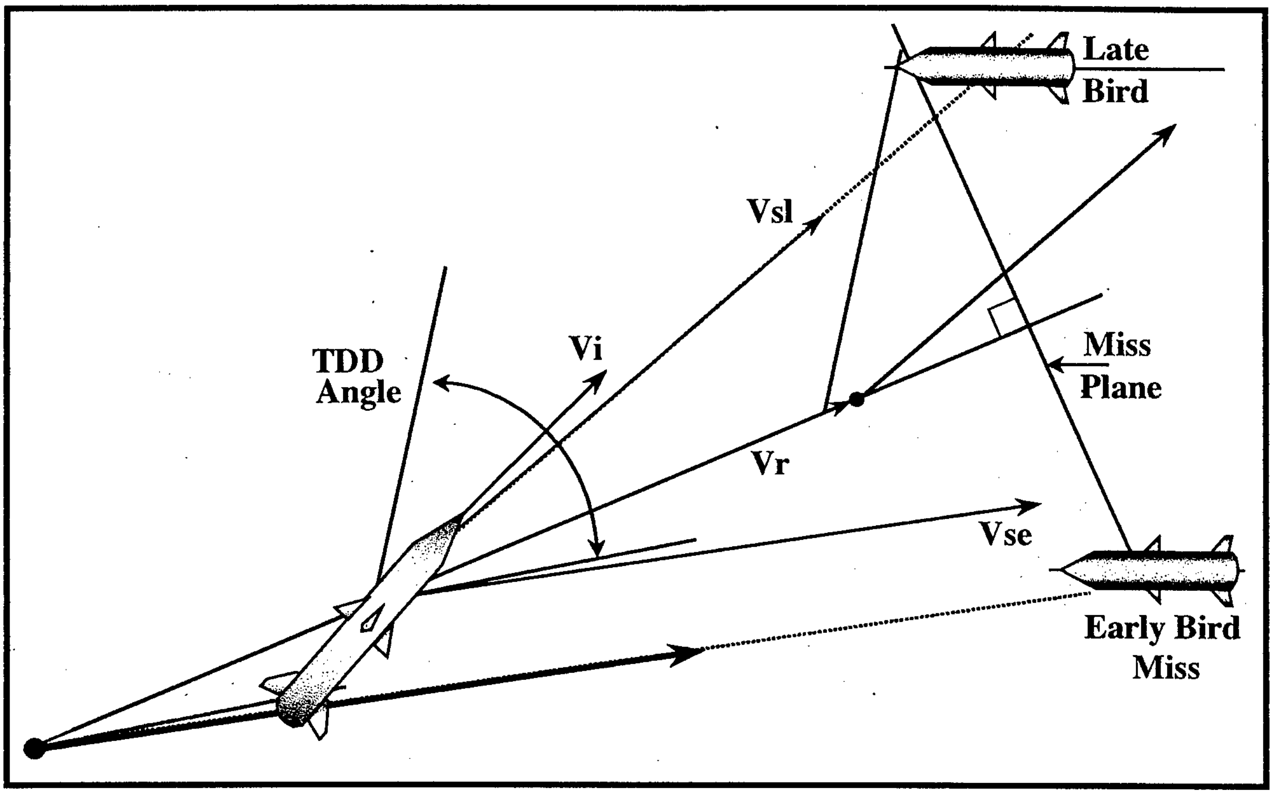


Figure 3. (U) Target Detection Considerations

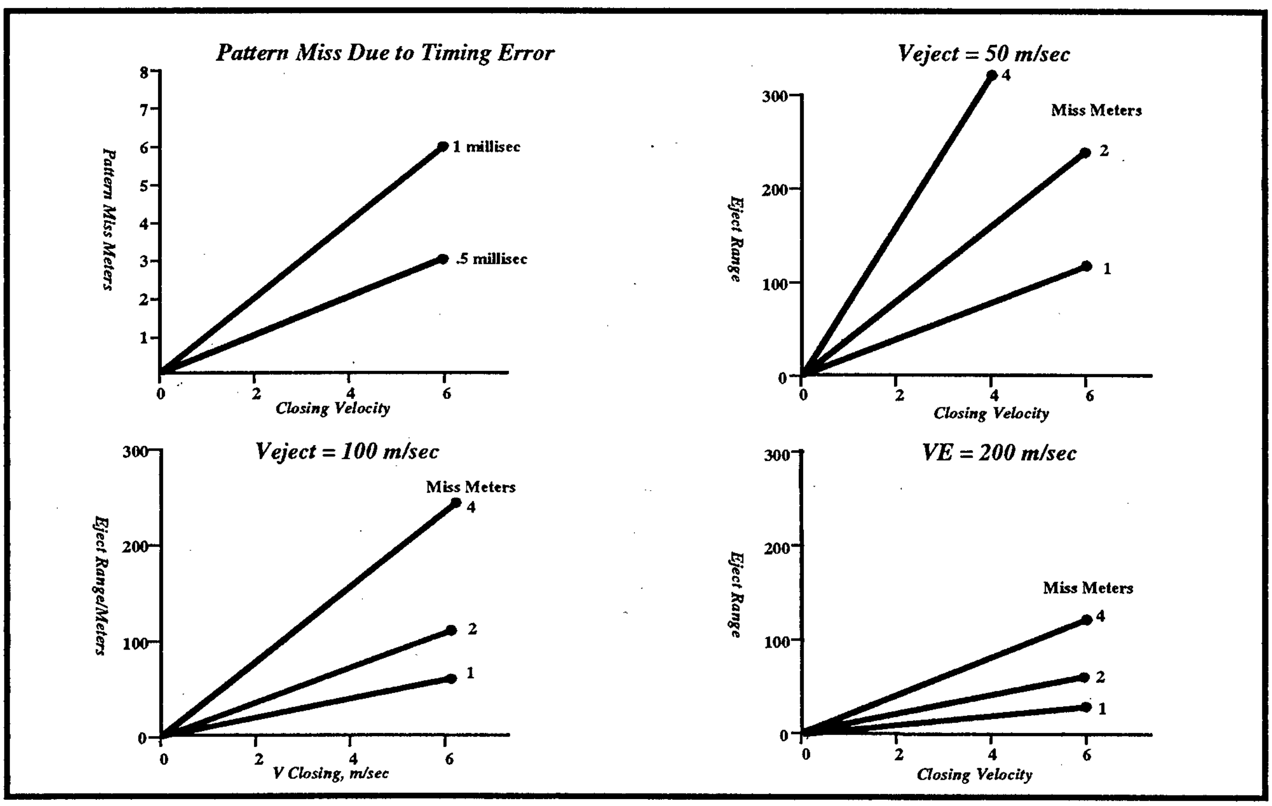


Figure 4. (U) Projectile Ejection Parametrics

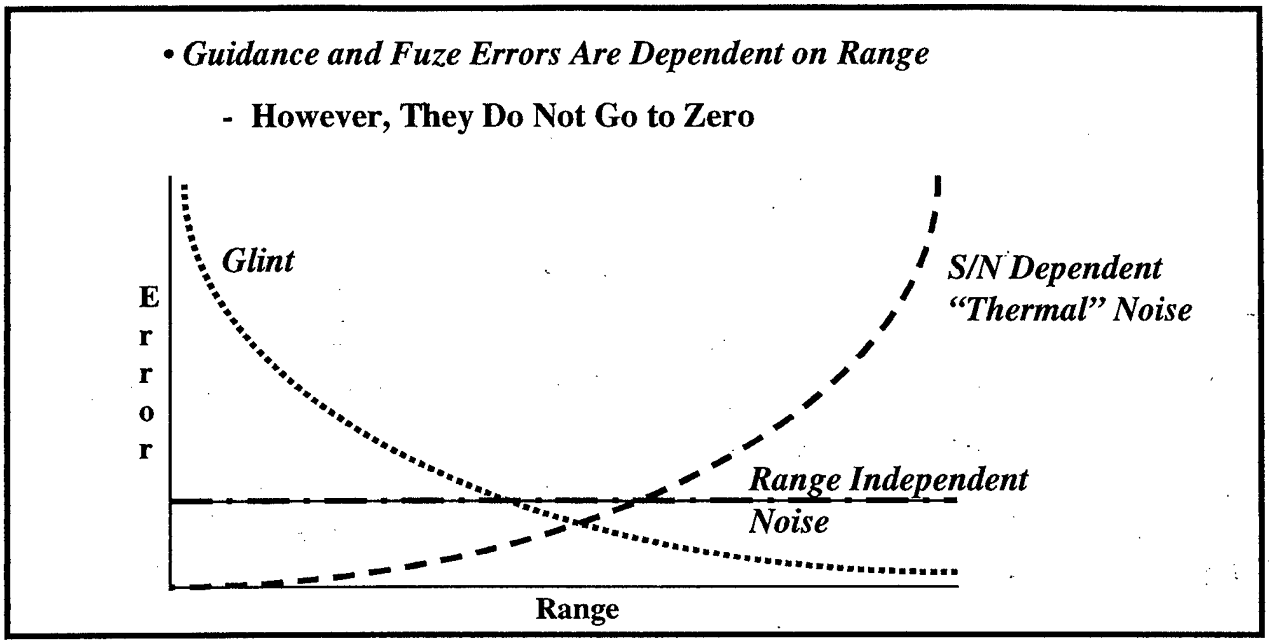
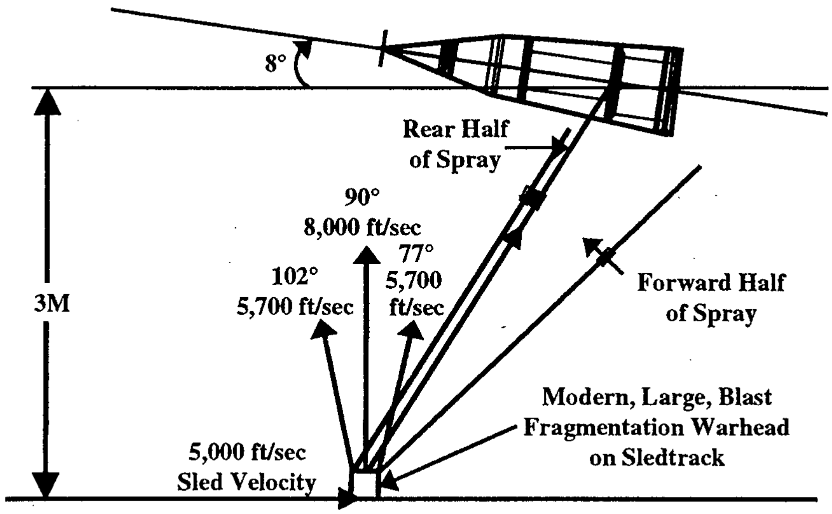


Figure 5. (U) Error Considerations

Figure 6. (U) Hit-to-Kill Test Result



Test Setup

Results

Figure 7. (U) Dynamic Warhead Test

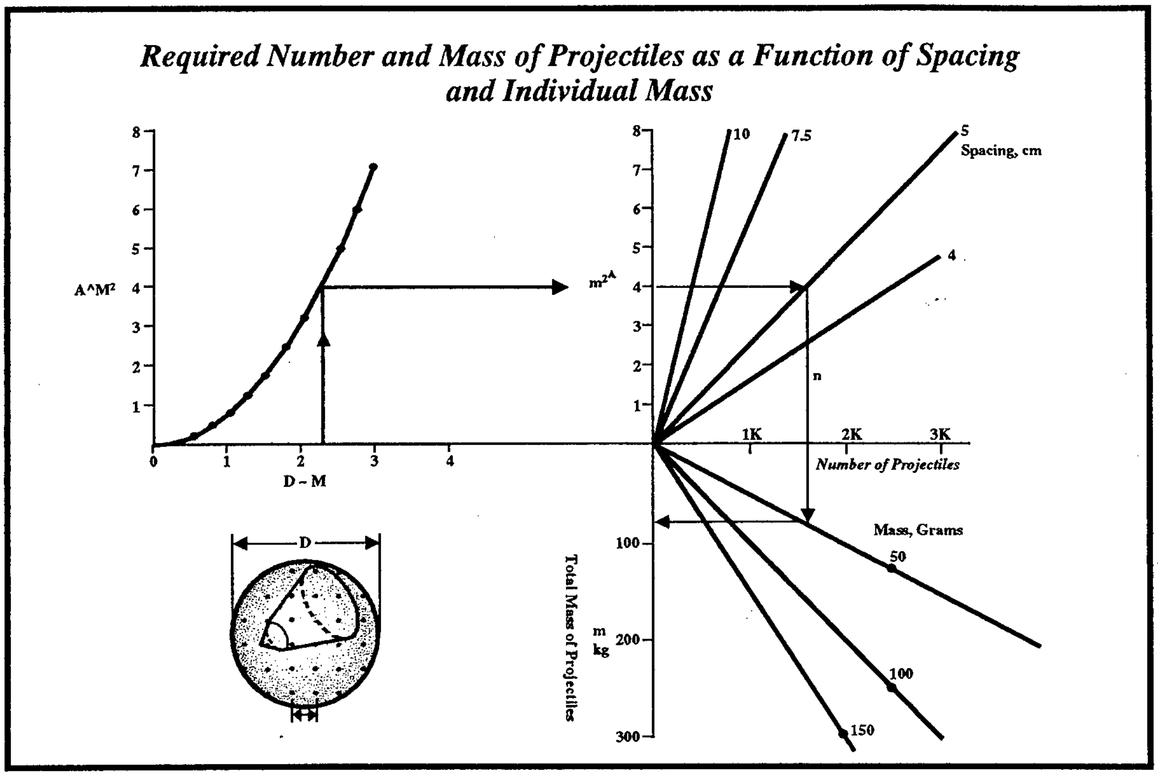


Figure 8. (U) Warhead Parametrics

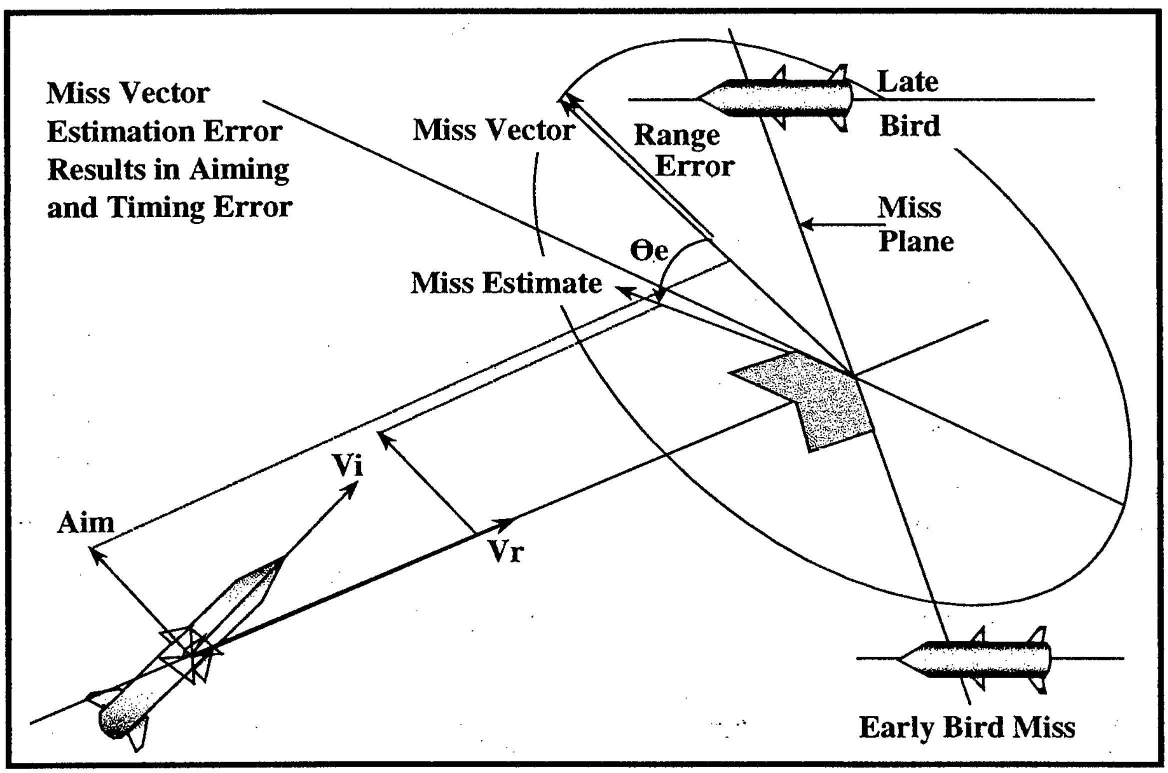


Figure 9. (U) Focused Warhead Aiming Requirements

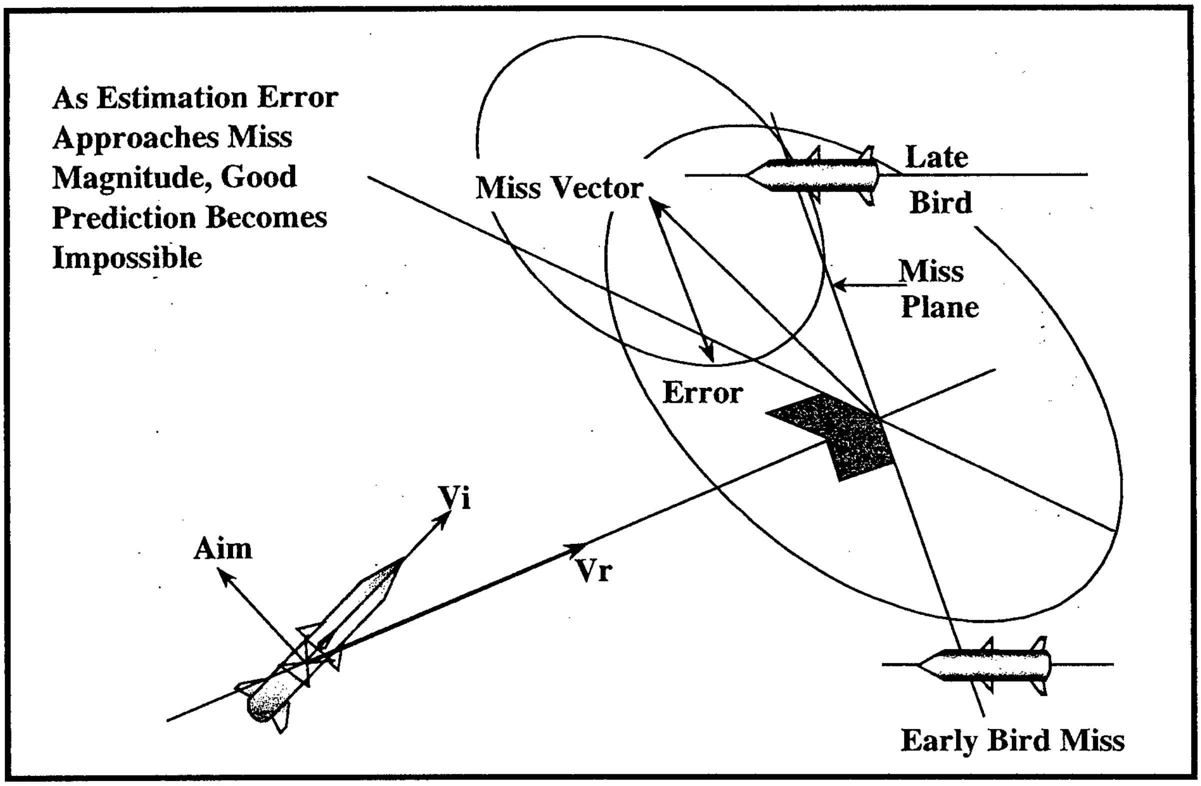
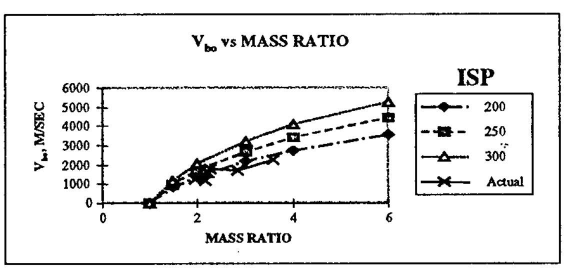


Figure 10. (U) Focused Warhead Aiming Requirements

Required Total Mass
in a Vacuum: $V_{bo} = Isp \bullet G \bullet Ln(R)$



V_{bo} **Burnout Velocity**
G **Gravitational Acceleration**
Isp **Specific Impulse**
R **Total Mass /Burnout Mass**

Figure 11. (U) Implications of Warhead Solution